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Behavioral states and state related heart rate and motor activity patterns in the newborn infant and the fetus antepartum – A comparative study. I. Technique, illustration of recordings, and general results

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Numerous proposals for ante partum assessment of fetal wellbeing have been published in the past years and recently special attention has been directed towards refined methods of FHR evaluation as well as methods of fetal movement count [8–11, 13, 14, 17, 23, 24, 26–29, 32, 39, 41–47, 49, 51, 54, 55, 59]. Unfortunately in these publications possible influences of spontaneous changes of central nervous coordination on FHR and fetal motor activity have not been taken into account.

The existence of spontaneous changes in CNS coordination, i.e. the existence of behavioral states or states of „sleep" and „wakefulness" in the fetus has been postulated for some time [14, 18, 60]. But there are some reasons why we do not have precise knowledge about the relation between behavioral states in the human fetus and state specific FHR and motor activity patterns. First of all fetal state behavior cannot be assessed by direct observation. Therefore indirect methods have to be applied in this research field. Drawbacks of animal experiments on this topic [3, 4, 21, 25, 40] are differences in species cerebral maturation and species specific heart rate pattern. Another indirect method would be to compare state specific heart rate and motor activity patterns of healthy human newborn infants with patterns seen in the unstressed fetus.

Neuropediatricians have accumulated a vast amount of knowledge about state behavior in the newborn infant by combination of direct observation of the infant and polygraphic recording of a set of parameters including EEG, EOG, EMG, respiration and heart rate [5, 6, 12, 19, 30, 31, 33–35, 37, 37a, 48, 50, 52, 53, 62].

According to PRECHTL [19,35] five states are defined:

State 1: eyes closed, no movements under the lids, regular respiration, no movements except sudden generalized startles

State 2: eyes closed, eye movements under the closed lids, irregular respiration, small muscular twitches, no gross movements

(State 2/4: same as above but interspersed gross movements)

State 3: eyes open, no gross movements

State 4: eyes open, movements of head, limbs and trunk

State 5: Crying

(State 1 grossly corresponds to NREM-sleep, quet sleep or regular sleep, state 2 grossly corresponds to REM-sleep, active sleep or irregular sleep [19].

In several publications state related changes of the newborn infant's heart rate pattern have been demonstrated, but neuropediatricians usually evaluate heart rate [36, 37, 37a, 57, 58] on a beat-to-beat-interval basis and statistic data presented are measures of location and dispersion of beat-to-beat-interval histograms or measures of time series

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analyses. In only one publication spectra for heart rate variability in cycles per min are demonstrated [16]. Contrary to that obstetricians evaluate FHR in respect to baseline level, amplitude and frequency of macrofluctuation and deviations from baseline, i.e. accelerations and decelerations. Therefore typical state related heart rate patterns in the newborn infant have to be reanalysed in respect to baseline level as well as amplitude and frequency of macrofluctuation and deviations. A comparative search for identical heart rate patterns in the human fetus, if successful, would prove the influence of CNS function on FHR pattern and this would improve our knowledge for correct interpretation of FHR patterns.

1 Material and methods

18 patients were selected for this evaluation (see Tab. I). Six patients were hospitalized because of mild HEP-syndrome (in all of them at the time of FHR recording symptoms were restituted to normal after bed rest and in some of them after medication of diuretics for some days). Nine patients were postterm, being 41/4 to 42/5 weeks of gestation. One had a history of caesarean section, in one there was suspicion of cervical incompetence. In two anencephaly had been diagnosed, and both fetuses died during parturition.

In one of our earlier studies on postmaturity we had seen, that statistical relevant effects of postmaturity (i.e. signs of fetal distress), if any, could only be seen in patients more than one week overdue. We again subdivided according to this borderline.

The 16 babies of our selected patients served as control group for neonatal heart rate recording. As to these infants no special events have to be reported except that in 5 infants intermittent hyperbilirubinemia occurred. In 4 of these bilirubin was back to normal at the time of recording, in one (008) it was still persistent and light therapy was applied. One baby (017) was slightly premature.

1.1 Recording procedure

For the time of FHR recording patients were kept in bed. They were allowed to lay either side or, for

Tab. I. Patient data

CASE NR	GROUP	INITIAL	AGE	PARITY	HISTORY OF PREGNANCY	MEDICATION	OESTRIOL MIN/MAX	PARTUS (WEEK) OF GESTATION	MODUS	♂♀	WEIGHT/ LENGTH	APGAR	CORD BLOOD pHa BEa	WEIGTH PLACENTA	TIME OF RECORDING FETUS WEEK OF GESTATION	DAYS BEFORE BIRTH	TIME OF RECORDING NEWBORN AGE IN DAYS	HYPER-BILIRUBIN-AEMIA DAY
001	B	J.W.	25	I	POSTTERM	./.	8.7- 9.0	42/4	SP	♂	4000/54	8/10/10	./.	./.	42/4	<1	5	
002	A	K.W.	24	II	SUSPICION OF CERVICAL INCOMPETENCE	./.	6.1-19.6	42/4	SP	♂	3050/49	9/10/10	7.12/-20.7	510	39/4	21	7	
003	A	M.B.	25	II	CAESAREAN SECTION IN HISTORY	./.	./.	41/4	C.S.	♀	3830/52	9/10/10	7.23/- 9.5	./.	41/3	1	13	
004	A	R.V.	19	I	POSTTERM	./.	./.	41/4	SP	♀	3980/47	9/10/10	./.	./.	41/3	1	5	2-4
005	A	H.M.	23	II	POSTTERM	./.	28.3	41/5	SP	♀	3970/51	8/ 9/10	7.34/- 9.1	755	41/4	1	7	
006	A	S.B.	26	I	POSTTERM	./.	./.	41/4	SP	♂	3080/48	9/10/10	7.28/- 8.2	450	41/2	2	5	
007	A	V.L.	31	II	MILD HE-SYNDROME	DIURETICS	5.2-18.7	42/2	SP	♀	3450/48	8/ 9/10	7.23/-10.4	580	41/4	5	5	3-4
008	A	G.K.	19	I	MILD HE-SYNDROME	DIURETICS	10.3-14.1	41/1	VE	♀	3380/48	8/ 9/10	7.26/-10.2	./.	39/4	9	4	3-5 LIGHT THERAPY
009	B	H.ST.	24	I	POSTTERM	./.	13.0-17.1	42/2	C.S.	♀	3400/49	9/10/10	7.11/-14.4	600	41/7	2	5	
010	B	N.E.	29	II	POSTTERM	./.	15.5	42/1	SP	♀	3040/47	9/10/10	7.26/-10.9	540	41/7	1	5	
011	A	R.W.	28	II	MILD HE-SYNDROME	DIURETICS	11.7-23.8	40/7	SP	♀	3950/52	9/10/10	7.22/- 6.3	./.	38/2	19	6	
012	B	H.T.	22	I	POSTTERM	./.	10.1-15.2	42/5	VE	♂	3880/53	9/10/10	7.25/- 8.8	550	42/3	2	5	3
013	A	H.Ö.	23	I	MILD HE-SYNDROME	DIURETICS	7.5-19.5	40/5	SP	♀	3900/53	9/10/10	7.26/-10.7	650	39/3	9	5	
014	C	I.ST.	27	I	ANENCEPHALY	./.	./.	39/2	SP		2380/44		./.	400	36/2	./.	./.	
015	C	L.G.	25	II	ANENCEPHALY	./.	./.	23/6	SP		420/27		./.	./.	23/1	./.	./.	
016	B	E.B.	27	I	MILD HE-SYNDROME POSTTERM	./.	./.	42/4	C.S.	♂	3810/51	3/10/10	7.08/-14.0	490	42/1	3	6	
017	A	R.O.	24	I	MILD HE-SYNDROME	./.	11.2-21.8	38/5	SP	♀	2840/48	10/10/10	7.30/- 8.6	500	37/4	8	5	2-4
018	B	R.G	23	I	POSTTERM	./.	8.5-22.5	42/4	VE	♀	3730/52	9/10/10	7.35/- 5.2	570	42/4	1	7	

shorter periods, on their back. Positions were noted on the strip chart.

Instantaneous fetal heart rate, derived from abdominal fetal ECG and the external tocogram were recorded on HEWLETT-PACKARD 8021 A cardiotocograph strip chart with 1 cm/min time base. **Fetal motor activity** was recorded by the patient marking every fetal movement she felt with a push button causing a 1 volt spike from a battery box. FECG, a heart beat synchronous pulse, fetal heart rate, **tocogram and fetal movements** were recorded on analog tape (AMPEX PR 2200). Recording lasted 8 hours, beginning in the morning and ending in the afternoon.

At least 4 days after parturition, when adaptation to extrauterine life had led to central nervous and cardiovascular homoiostasis and when the influence of intrapartum medication was eliminated the same individuae, now newborn infants, were observed for assessment of newborn infant state behavior and state related heart rate and motor activity patterns. Electrodes were attached to the chest for recording of instantaneous heart rate via ECG and respiration via impedance pneumography. The babies were swaddled comfortly and transfered into an incubator to assure constant environmental conditions with temperature at 30° to 32 °C and humidity at 55%. Again electrodes were connected to a HEWLETT-PACKARD 8021 A cardiotocograph for recording of heart rate in the same way as in the fetus and they were connected to an impedance pneumograph (HELLIGE). ECG, a heart beat synchronous pulse, heart rate and respiration again were recorded on analog tape (AMPEX PR 2200) too. The recording procedure, was begun after feeding in the evening and ended in the early morning, again lasting 8 hours. In all newborn except 001 during the whole time close observation and protocol of the newborn's behavioral states and all interesting events was performed along with the recording.

1.2 Analysis

After each recording procedure compressed strip chart records of heart rate, movement marks and tocogram (fetus) or heart rate and respiration (newborn) were generated by play back from tape. Secondly all analog recordings of heart rate were digitized with 2 Hz sample rate and data of sequential segments of 1 min (= 480 segments per recording) were analysed in respect to baseline level as well as amplitude and frequency of macrofluctuation. This was done according to quantification methods developed by the author [12]. The computer program (hp BASIC) for automatic control of 1 min-segment-by-segment play back from tape via SYSTRON DONNER Model 8140 Tape Search Unit, digitizing (INTERTECHNIQUE Model Physiosope) and computing of baseline level, amplitude and frequency of macrocluctuation (HEWLETT-PACKARD Model 9830 A Minicomputer) had been written by the author. (Because of restriction in hard ware power the author's program did not automatically define and sort out deviations from baseline level, i.e. accelerations and decelerations). Output of data was done in the form of tables (HEWLETT-PACKARD 9866 Printer) and sequential histogram plots (HEWLETT-PACKARD 9862 Plotter). Output data were stored on tape casette for further statistical analysis as well. The latter was performed on the 9830 A computer with HEWLETT-PACKARD standard statistical programs, whose input-output files in some cases were modified to allow direct, i.e. faster interprogram I/O operation.

Combined evaluation of original as well as compressed strip chart records of the newborn infants' heart rate and respiration in connection with the protocols of direct observation of state behavior and motor activity allowed identification of NREM-sleep, REM-sleep and wakefulness and definition of state related patterns of heart rate. (The states of wakefulness were not evaluated in detail because discrimation between these states is dubious in the fetus for obvious reasons).

Statistical analysis of state related differences in baseline level as well as amplitude and frequency of macrofluctuation supported our definitions. (Statistics were performed on the HEWLETT-PACKARD Model 9830 A Minicomputer with the One Sample Nonparametric Program of the HEWLETT-PACKARD Statistics Library).

After we had learned to identify states in our recordings of newborn infants by visual analysis and by statistical evaluation of heart rate, the same procedure was applied to FHR recordings and we were able to identify FHR segments, that were characteristic and comparable to newborn heart rate in NREM-sleep, REM-sleep and wakefulness. Definition of states according to typical heart rate patterns in the fetus was supported by taking into account fetal movement marks too.

2 Results

2.1 Evaluation of the newborn infant's state behavior

2.1.1 The newborn infant's state behavior and state related heart rate patterns illustrated

Polygraphic recordings of state related patterns of physiological parameters as heart rate, respiration and others in the newborn have been demonstrated elsewhere in detail [35, 53]. Still, there is reason to

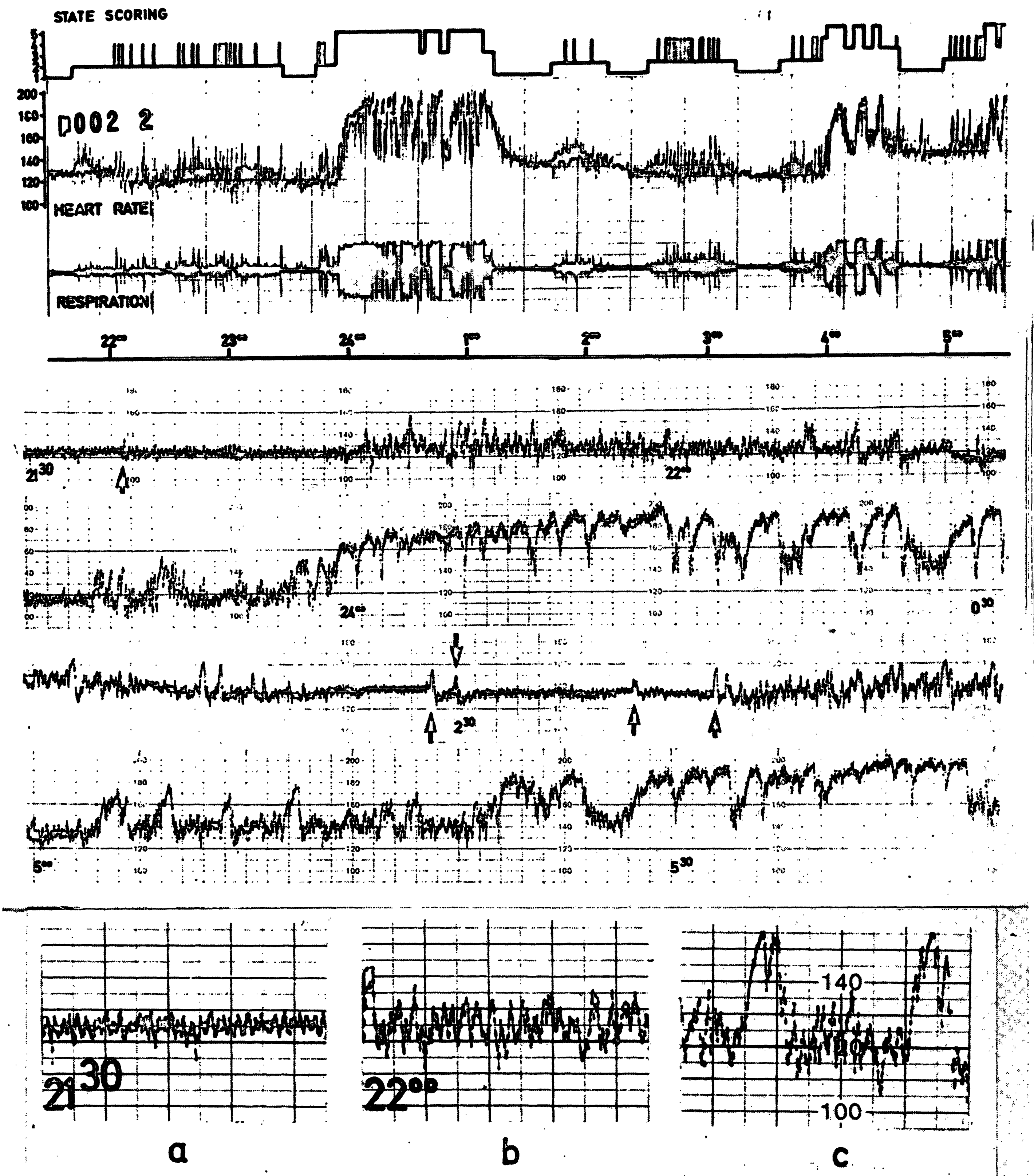


Fig. 1. Newborn infant (002)

Top: Compressed writeout of 8 hour recording of heart rate and respiration together with state scoring from observational notes.
In the compressed record well defined changes of heart rate and respiration coincide with changes in observational state scoring. Changes between NREM-sleep and REM-sleep occur in a fairly regular sequence, although sometimes a transition from REM-sleep seems to be going on but is not followed by NREM-sleep at last (~22.25 h). Gross body movements

demonstrate some of our recordings here. The main aim of this work was to search for state behavior and state related heart rate patterns in the human fetus on the basis of comparison and analogy. This can be done more easily, when both fetal and newborn heart rate tracings are recorded with the same recording machine, i.e. when tracings are identical in respect to time base and amplification. Moreover, because results will be most interesting and important for the obstetrician, as they will aid him in correct visual analysis and interpretation of FHR recording, both fetal and newborn heart rate tracings were recorded with the HEWLETT-PACKARD cardiotocograph, a machine used in many obstetric departments.

For a detailed demonstration of all peculiarities of some patterns, copies from original recordings may be less suitable. In that case the technique of playback from tape and writeout of compressed or extended records is of great advantage. When applying this method the illustrating effect is enhanced by adding corresponding segments of the original record for comparison.

From the compressed records in Fig. 1 a cyclic change of pattern in heart rate and respiration can be seen. As evaluated from the observational notes these changes are synchronous with changes in the newborn infant's state.

First of all from the compressed records as well as from the original strip charts it can be seen that **during NREM-sleep baseline in general is stable or slowly lowering. Small accelerations or acceleration-deceleration patterns are synchronous with startles,** a phenomenon that has been described by neuropediatricians in detail [11, 35]. **During REM-sleep it is more difficult to define baseline visually, because overall baseline is less stable.** During state 4 and state 5 heart rate is grossly altered. **During wakefulness with gross body movements accelerations of large amplitude, synchronous with motor activity, are repetitive and often merging** so that heart rate rises abruptly and the high level can often be taken as a sequence of peaks of these repetitive and merging accelerations with their interspersed downward and upward slopes. **In the vigorously crying infant a marked and more or less straightlined tachycardia is present.** In our opinion this elevated heart rate should not be taken as "baseline" in strict sense.

Changes in the pattern of macrofluctuation related to sleep state changes can be seen clearly. From the original heart rate writeout at 1 cm/min shown below the compressed records it can be seen that in general the macrofluctuation pattern in NREM-sleep is of lower amplitude (in beats per min) and higher frequency (in cycles per min) compared to the macrofluctuation pattern in REM-sleep. Besides a higher amplitude and a slightly lower frequency in REM-sleep there is more variation in both and identifying small accelerations within this pattern is difficult unless an obvious state 2/4 occurs, i.e., when interspersed gross movements of body and/or limbs give rise to accelerations with quite large amplitude and duration. The heart rate pattern

during REM-sleep (state 2/4) are marked by upstrokes in the state scoring. Periods of wakefulness occur about midnight and in the early morning, when the baby is fed and swaddled.
Center: 4 segments of original heart rate writeout (HEWLETT-PACKARD machine at 1 cm/min speed), each of 45 min duration.
In the first segment at the left a NREM-sleep heart rate pattern is seen. One startle, marked by an arrow occurs. At 21.45 h a change to pure REM-sleep pattern occurs, gross body movements and with that accelerations of larger amplitude are absent.
The second segment again starts with a NREM-sleep pattern. Three minutes later REM-sleep begins. Body movements are noted and with them accelerations can be seen. 2 min before midnight the baby wakes up and it starts crying almost immediately. Heart rate rises and the pattern can be taken as a sequence of peaks of repetitive and merging accelerations with their interspersed downward and upward slopes. Sometimes between accelerations heart rate goes down to normal baseline level for short periods. The third segment starts with a transition from REM- to NREM-sleep and during the following NREM-sleep pattern 4 small accelerations synchronous with startles are marked by arrows. Immediately after the last marked startle a change to REM-sleep pattern occurs. The first half of the last segment shows a REM-sleep pattern with interspersed accelerations synchronous with body movements (state 2/4). This is followed by wakefulness again.
Bottom:
a) Macrofluctuation pattern during NREM-sleep
b) Macrofluctuation pattern during REM-sleep
c) Macrofluctuation pattern during REM-sleep with interspersed accelerations from gross body movements (state 2/4).

during state 4 and state 5, consisting of repetitive or merging accelerations to our opinion should not be taken as macrofluctuation. Macrofluctuation during states 4 or 5 can only be identified, when between accelerations heart rate goes down to the normal baseline level for short periods.

Alterations of these typical macrofluctuation patterns in the newborn infant's heart rate may be caused by additional influences such as periodic respiration or respiratory arrhythmia. (These alterations of macrofluctuation pattern together with identical macrofluctuation patterns seen in FHR recordings will be presented in a separate publication).

2.1.2 Overall distribution of state duration in the newborn infant in 8 hours recordings

According to literature [19, 53] **the newborn infant is asleep 17 to 20 hours a day, which is 70 to 83% of time, spending 75% of total sleeping time in REM-sleep.**

In Tab. II total and relative times spent in NREM-sleep, REM-sleep and wakefulness are given for all newborn infants. Because there was no statistical difference in data of group A and B, they were pooled. Our data are in complete agreement with literature data. In 76.9% of total recording time (14 X 8 hours) the babies were asleep and 26.6% of total sleeping time was defined as NREM-sleep.

2.1.3 Duration of sleep cycles and ratio of NREM- and REM-sleep within sleep cycles

According to literature [12, 19, 50, 52] **in the newborn infant duration of a sleep cycle (a cycle of NREM- + REM-sleep) is 45 min to 2 hours. Periods of NREM-sleep last 10 to 20 min and periods of REM-sleep last 20 to 45 min.**

In Tab. III mean values as well as minimal and maximal values for absolute duration of sleep cycles and for absolute durations and relative fractions of NREM- and REM-sleep periods are given. In our recordings mean duration of sleep cycles was 61.9 min, mean duration of NREM-periods was 18.5 min (= 29.8% of total duration of cycle) and mean duration of REM-periods was 43.2 min. Again

Tab. II. Distribution of state duration in 8 hour recordings newborn infants

CASE NR	STATE 1	STATE 2	STATE 3-5	TOTAL SLEEPING TIME	STATE 1 WITHIN TOTAL SLEEPING TIME
002	113 min (23.5 %)	231 min (48.1 %)	136 min (28.3 %)	344 min (71.6 %)	32.8 %
003	69 min (14.3 %)	158 min (32.9 %)	253 min (52.7 %)	227 min (47.2 %)	30.3 %
004	140 min (29.1 %)	210 min (43.7 %)	130 min (43.7 %)	350 min (72.9 %)	40.0 %
006	43 min (8.9 %)	240 min (50.0 %)	197 min (41.0 %)	283 min (58.9 %)	15.1 %
007	113 min (23.5 %)	292 min (60.8 %)	75 min (15.6 %)	406 min (84.5 %)	27.9 %
008	94 min (19.5 %)	318 min (66.2 %)	68 min (14.1 %)	412 min (85.8 %)	22.8 %
009	124 min (25.8 %)	274 min (57.0 %)	82 min (17.0 %)	398 min (82.9 %)	31.1 %
010	66 min (13.7 %)	296 min (61.5 %)	118 min (24.5 %)	362 min (75.4 %)	18.2 %
011	73 min (15.2 %)	363 min (75.6 %)	44 min (9.1 %)	436 min (90.8 %)	16.7 %
012	95 min (19.7 %)	359 min (74.7 %)	26 min (5.4 %)	454 min (94.5 %)	20.9 %
013	117 min (24.3 %)	293 min (61.0 %)	70 min (14.5 %)	410 min (85.4 %)	28.5 %
016	90 min (18.7 %)	202 min (42.0 %)	188 min (39.1 %)	292 min (60.8 %)	30.8 %
017	135 min (28.1 %)	315 min (65.6 %)	30 min (6.2 %)	450 min (93.7 %)	30.0 %
018	106 min (22.0 %)	242 min (50.4 %)	132 min (27.5 %)	348 min (72.5 %)	30.4 %
TOTAL	1378 min (20.5 %)	3793 min (56.4 %)	1549 min (23.0 %)	5172 min (76.9 %)	26.6 %

Tab. III. Duration of sleep cycles, absolute and relative duration of state 1 and state 2 periods within sleep cycle
Newborn infants

CASE NR	NUMBER OF SLEEP CYCLES EVALUATED	MINIMUM DURATION OF SLEEP CYCLES	MAXIMUM DURATION OF SLEEP CYCLES	MEAN DURATION OF SLEEP CYCLES	MINIMUM DURATION OF STATE 1	MAXIMUM DURATION OF STATE 1	MEAN DURATION OF STATE 1 (% OF CYCLE)	MINIMUM DURATION OF STATE 2	MAXIMUM DURATION OF STATE 2	MEAN DURATION OF STATE 2 (% OF CYCLE)
002	5	36 min	123 min	64.0 min	17 min	24 min	19.6 min (36.4 %)	21 min	105 min	44.4 min (63.5 %)
003	3	49 min	65 min	59.6 min	10 min	19 min	15.3 min (26.9 %)	30 min	55 min	44.0 min (73.0 %)
004	5	36 min	69 min	56.6 min	10 min	44 min	27.2 min (45.8 %)	25 min	35 min	29.4 min (54.1 %)
006	4	27 min	78 min	59.2 min	9 min	15 min	10.7 min (21.4 %)	17 min	69 min	48.5 min (78.5 %)
007	4	45 min	185 min	86.5 min	17 min	34 min	24.2 min (37.3 %)	22 min	162 min	62.2 min (62.7 %)
008	5	46 min	104 min	66.6 min	7 min	25 min	18.0 min (29.3 %)	21 min	80 min	48.6 min (70.6 %)
009	6	41 min	86 min	59.5 min	17 min	24 min	20.6 min (35.8 %)	24 min	62 min	38.8 min (64.1 %)
010	5	23 min	120 min	55.4 min	5 min	25 min	13.2 min (31.3 %)	11 min	111 min	42.2 min (68.6 %)
011	4	38 min	138 min	81.5 min	6 min	24 min	18.2 min (23.2 %)	32 min	117 min	63.2 min (76.7 %)
012	3	32 min	117 min	87.6 min	16 min	31 min	22.6 min (31.7 %)	16 min	96 min	65.0 min (68.2 %)
013	6	32 min	78 min	50.5 min	9 min	25 min	19.5 min (43.2 %)	10 min	56 min	31.0 min (56.6 %)
016	2	28 min	43 min	35.5 min	5 min	26 min	15.5 min (39.1 %)	17 min	23 min	20.0 min (60.8 %)
017	5	37 min	91 min	67.4 min	12 min	26 min	19.2 min (24.0 %)	16 min	75 min	48.2 min (71.5 %)
018	7	16 min	94 min	47.4 min	10 min	24 min	15.1 min (37.5 %)	6 min	74 min	32.2 min (62.3 %)
	TOTAL 64			WEIGHTED MEAN 61.9 min			WEIGHTED MEAN 18.5 min (29.8 %)			WEIGHTED MEAN 43.2 min (69.9 %)

data are in good agreement with data cited from literature.

2.1.4 Evaluation of motor activity in the newborn infant in respect to sleep state

Close observation of the newborn infants during 8 hours recordings revealed a striking difference in motor activity during different states. During NREM-sleep, motor activity generally is absent except for the occurrence of startles, fully or abortive, single or sometimes repetitive. **Gross movements in NREM-sleep with larger accelerations are very rare. During REM-sleep motor activity is enhanced.** Small muscular twitches do not alter the typical heart rate pattern of a pure REM-sleep but besides these small twitches single or sequences of gross movements of limbs and even trunk do occur. This has led to the definition of state 2/4 in literature [19, 35]. Synchronous to these movements accelerations of heart rate can be seen and, as there is a wide range as to the amount and pattern of movements there is a wide range of acceleration patterns in respect to amplitude, duration and frequency. The ratio of movement counts per duration of NREM- and REM-states was .129 and .391 respectively. The difference is statistically significant: motor activity is 3 X higher in REM-sleep compared to NREM-sleep.

3. Evaluation of fetal state behavior

As has been said in our introduction fetal state behavior cannot be assessed by direct observation. Our approach to solve the problem must be indirect and it is based on the assumption that comparable neonatal and fetal heart rate and motor activity patterns are related to comparable states in the newborn infant and the fetus. To prove that comparable heart rate patterns do exist in the neonate and in the fetus, first of all some examples of our FHR recordings will be presented here. Secondly general results of comparing neonatal heart rate and FHR patterns will be presented. A presentation of our computer analysis in respect to heart rate patterns will be published elsewhere [22].

3.1 Fetal heart rate patterns and assumed related state behavior illustrated

Compressed 8 hour FHR records first of all show known technical limitations of abdominal FECG-

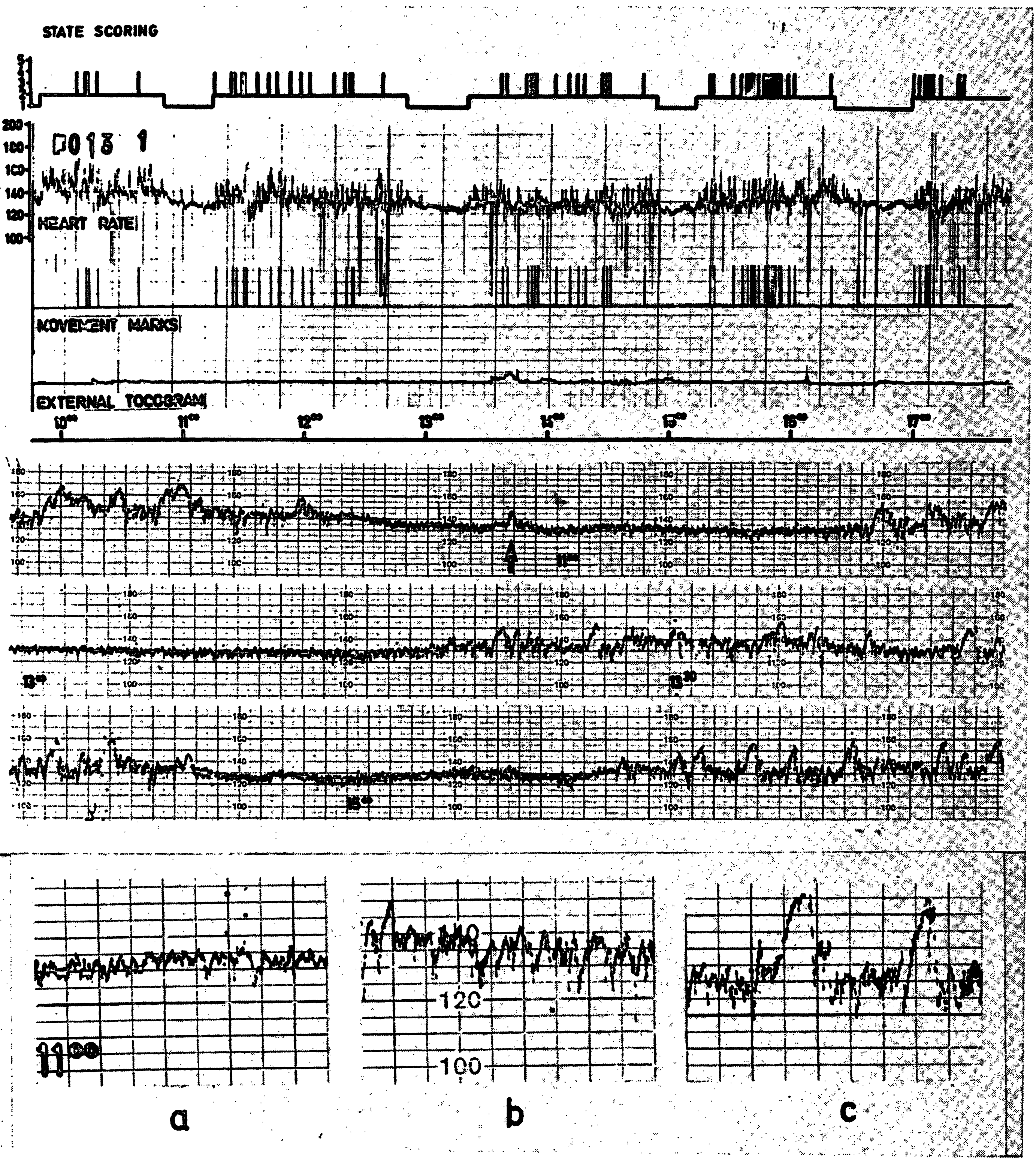


Fig. 2. Fetus (013)

Top: Compressed writeout of 8 hours recording of FHR, movement marks and external tocogram together with assumed state scoring.

In the FHR recording a regular change in macrofluctuation pattern can be seen clearly. The low amplitude macrofluctuation pattern corresponds to a heart rate pattern seen in the newborn infant during NREM-sleep and the pattern with higher amplitude and accelerations corresponds to a heart rate pattern seen in the newborn during REM-sleep (state 2/4). Thus identical or comparable states may be assumed in the fetus. Movement marks are state related: they are seen in REM-sleep and are absent (or rare) in NREM-sleep. A FHR pattern corresponding to a newborn heart rate pattern during wakefulness is not seen in this case.

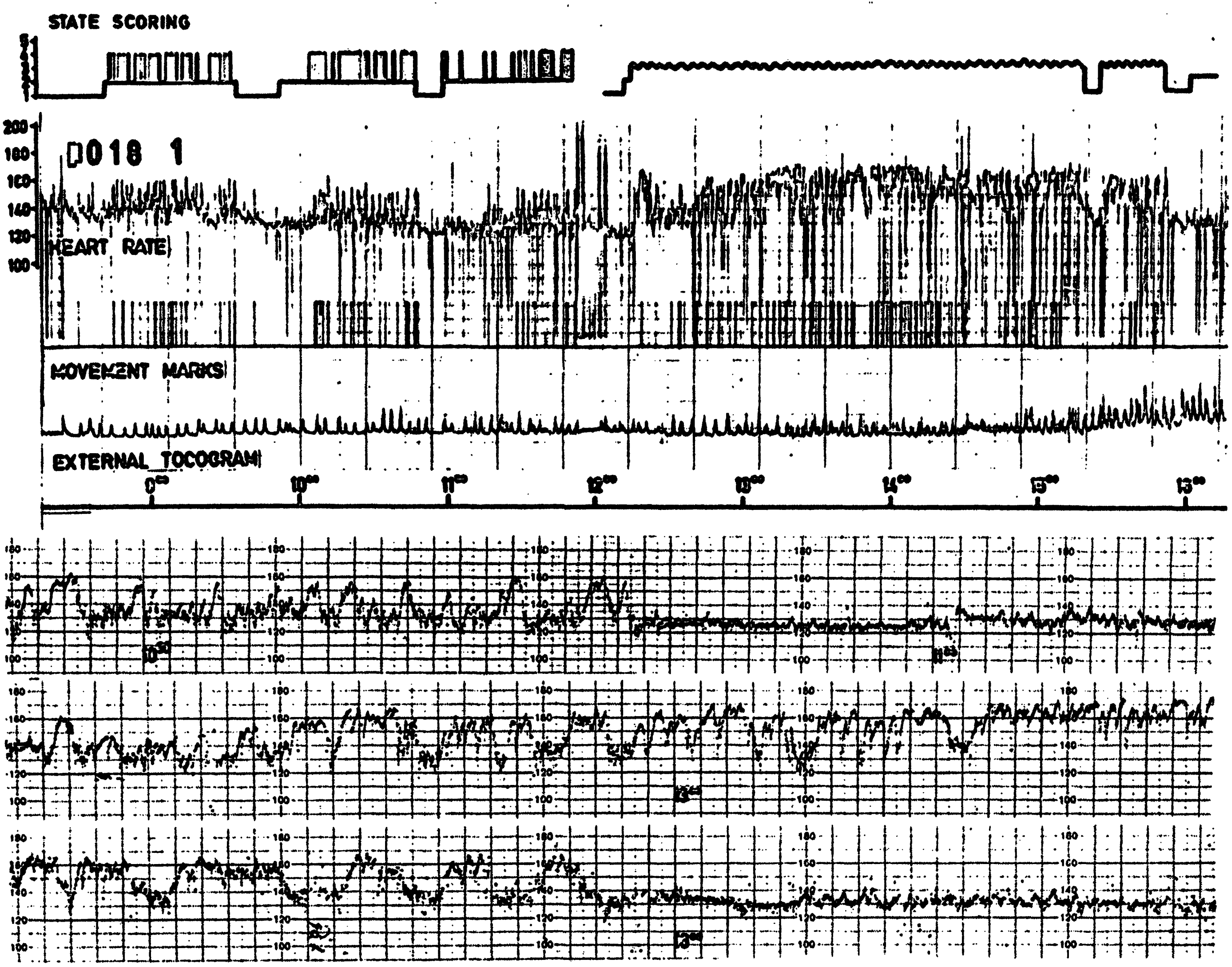
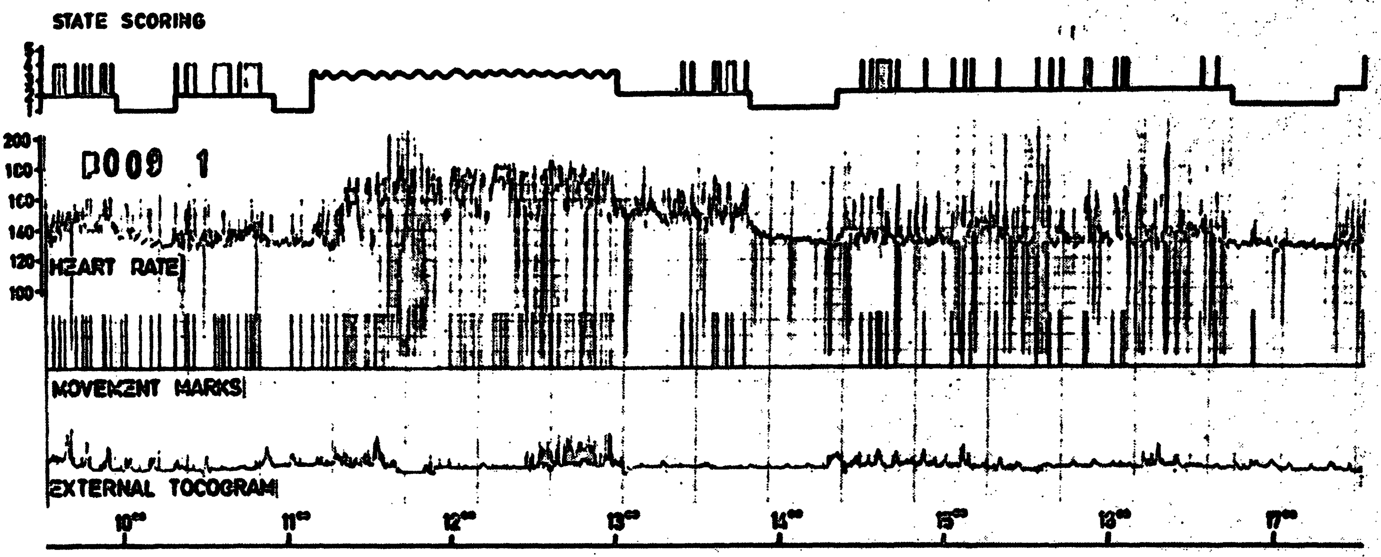
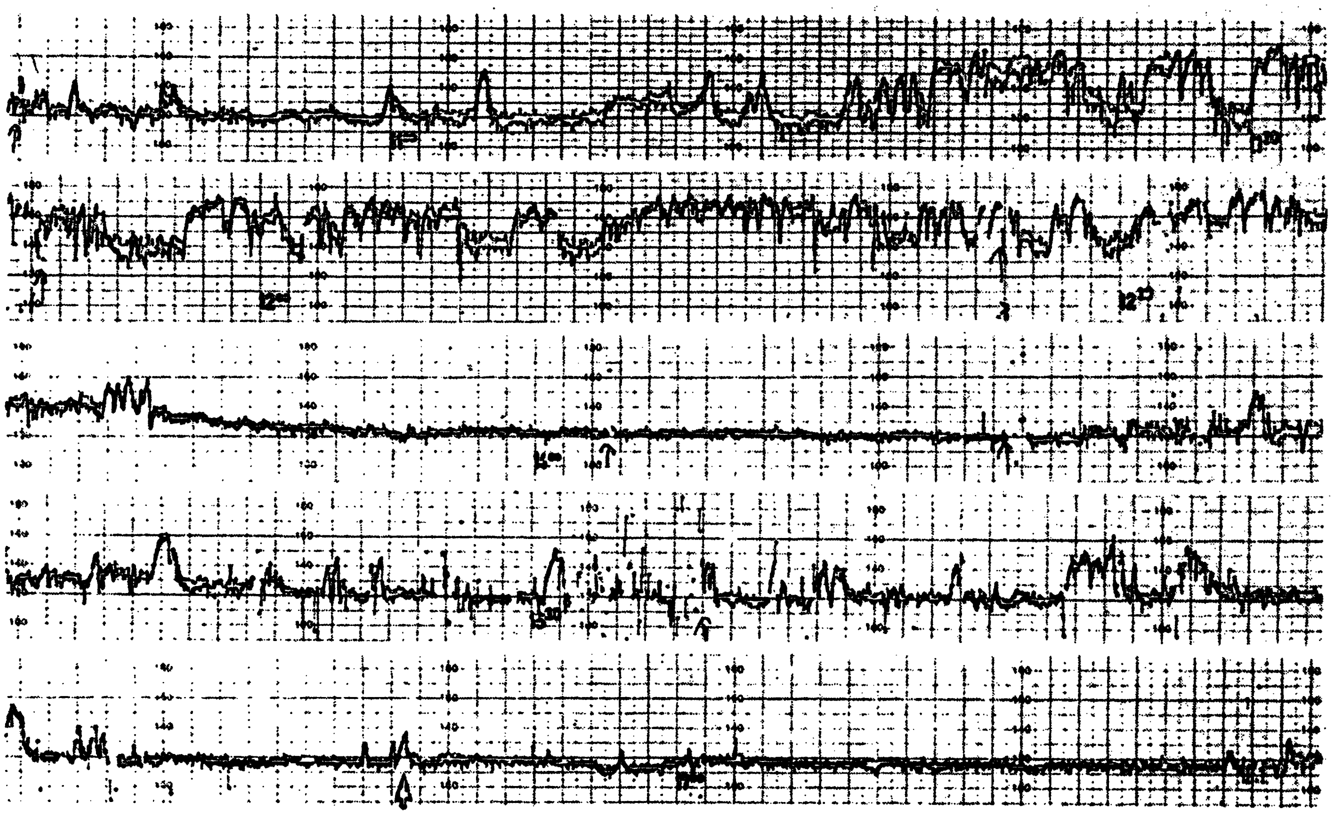
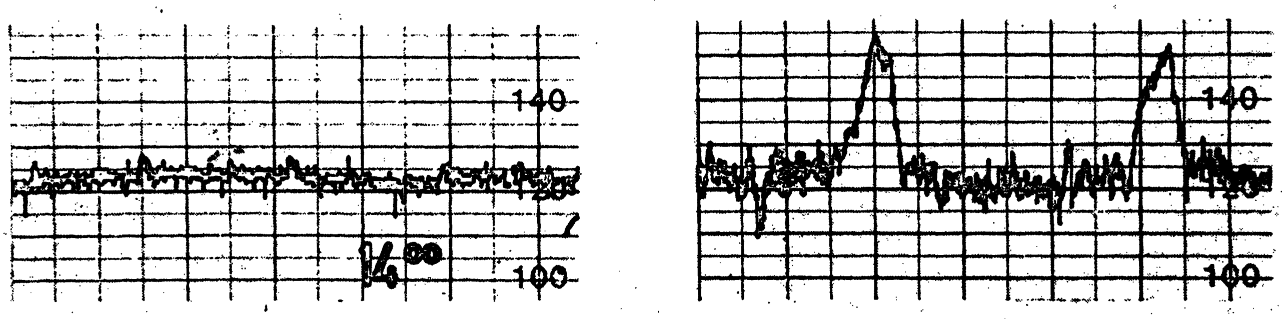


Fig. 3. Fetus (018)
Top: Compressed writeout of 8 hour recording of FHR, movement marks and external tocogram together with assumed state scoring.
The fetus is postterm (group B). Besides a regular change in FHR macrofluctuation as in the recordings demonstrated before, a long lasting period of FHR alteration, identical to the newborn heart rate pattern during wakefulness is seen (marked by in the state scoring). Movement marks are much more frequent compared to tracings shown before.
Bottom:
3 45-min-segments of original FHR writeout (HEWLETT-PACKARD machine at 1 cm/min speed).
Upper tracing: a REM-sleep macrofluctuation pattern with interspersed accelerations (state 2/4) is followed by a NREM-sleep pattern and again by a REM-sleep pattern. Middle tracing and left side of lower tracing: FHR pattern of "wakefulness".

Center: 3 segments of 45 min duration of original FHR writeout (HEWLETT-PACKARD machine at 1 cm/min speed). FHR macrofluctuation pattern during assumed NREM-sleep (middle part of upper segment, left side of middle segment, middle part of lower segment) and assumed REM-sleep is seen. One small acceleration in the upper segment during NREM-sleep (arrow) is assumed to be caused by a startle. Accelerations during REM-sleep (rhight side of lower segment) are synchronous with movement marks (state 2/4).
Bottom:
a) Macrofluctuation pattern during assumed NREM-sleep
b) Macrofluctuation pattern during assumed REM-sleep
c) Macrofluctuation pattern during assumed REM-sleep with interspersed accelerations from body movements (state 2/4).


STATE SCORING
D009 1
200
140
120
100
HEART RATE
EXTERNAL TOCOGRAM




140
100
140
100

a

b

derived FHR recording. Interspersed trigger errors appear as downstrokes. Clusters of trigger errors occurred with enhanced maternal (or fetal) motor activity.

In fetuses of group A FHR patterns comparable to neonatal NREM- and REM-patterns could be seen clearly (Fig. 2) but a FHR pattern comparable to neonatal heart rate during wakefulness was absolutely rare.

One fetal recording showed a macrofluctuation pattern identical to that seen in a neonate with periodic respiration.

In recordings of group B fetuses (Fig. 3) some remarkable alterations could be seen. Firstly and surprisingly heart rate patterns seen during neonatal wakefulness were seen in FHR recordings of this group in the same percentage as in the newborns. They were associated with markedly enhanced motor activity, as can be seen from the density of movement marks. Secondly enhanced motor activity in group B fetuses modified FHR patterns during assumed sleep as well: A higher number of accelerations of larger amplitude and duration in connection with movements, i.e. a state 2/4 occurred in REM-sleep and similar accelerations even occurred in NREM-sleep. One could speak of a state 1/4. Therefore differentiation of sleep states turned out to be difficult or even dubious in 2 cases (010, 016). Last not least in only one of our group B recordings (009) FHR alterations, that are known to be signs of fetal distress could be seen. In assumed NREM-sleep macrofluctuation was minimal and these states were of slightly longer duration. In assumed REM-sleep macrofluctuation amplitude was dminished too (Fig. 4).

3.2 Overall distribution of state duration in the fetus in 8 hour recordings

3.2.1 The fetus near term (group A)

In Tab. IV total and relative times spent in assumed NREM-sleep, REM-sleep and "wakefulness" are given for the fetuses of group A. It can be seen that in 97.6% of total recording time (10 X 8 hours minus 19 min) FHR showed a pattern identical to the newborn NREM- or REM-sleep heart rate pattern. In 26.3% of total "sleeping time" a NREM-sleep heart rate pattern was found. A **pattern corresponding to wakefulness in the neonate was seen in only** 1.2% of total recording time. In 1 case a severe deceleration with consecutive reactive FHR alteration occurred when the patient sat up in bed to empty her bladder.

3.2.2 The postterm fetus (group B)

A striking difference in the overall distribution of states in 8 hour recordings was found comparing group A and B (see Tab. V). A heart rate pattern corresponding to neonatal wakefulness occurred

Fig. 4: Fetus (009)
Top: Compressed writeout of 8 hour recording of FHR, movement marks and external tocogram together with assumed state scoring.
The fetus is postterm (group B) and routine FHR monitoring prior to our recording gave rise to suspicion of beginning distress. A regular change in FHR pattern and with that assumed state change is seen. Motor activity is raised in the first half. In the second haft it is less, but definitely present.
Center: 5 segments of original FHR writeout (HEWLETT-PACKARD machine at 1 cm/min speed), each of 45 min duration.
Segment 1: starts with several minutes of a REM-sleep pattern, then a NREM-sleep pattern with 2 accelerations from movements and at last the beginning of a pattern of "wakefulness" is seen.
Segment 2: pattern of "wakefulness" throughout.
Segment 3: at the beginning and at the end a REM-sleep pattern. Inbetween a NREM-sleep pattern of 33 min duration with minimal macrofluctuation amplitude. No accelerations.
Segment 4: REM-sleep pattern with decreased macrofluctuation amplitude, but accelerations from movements are present.
Segment 5: NREM-sleep pattern of 39 min duration with minimal macrofluctuation amplitude. One small acceleration from a single movement (startle) is marked by an arrow.
Bottom:
a) Macrofluctuation pattern during assumed NREM-sleep
b) Macrofluctuation pattern during assumed REM-sleep with interspersed accelerations from body movements (state 2/4).

Tab. IV. Distribution of state duration in 8 hour recordings fetuses group A

CASE NR	STATE 1	STATE 2	STATE 3-5	DECELERATION + REACTIVE FHR ALTERATION	RECORDING DISTURBANCE NO STATE SCORING POSSIBLE	TOTAL SLEEPING TIME	STATE 1 WITHIN TOTAL SLEEPING TIME
002	117 min (24.3 %)	335 min (69.7 %)	28 min (5.8 %)			452 min (94.1 %)	25.8 %
003	150 min (31.2 %)	330 min (68.7 %)				480 min (100.0 %)	31.2 %
004	103 min (21.4 %)	366 min (76.2 %)			11 min	469 min (97.7 %)	21.9 %
005	167 min (34.7 %)	313 min (65.2 %)				480 min (100.0 %)	34.7 %
006	175 min (36.4 %)	302 min (62.9 %)			3 min	477 min (99.3 %)	36.6 %
007	109 min (22.7 %)	366 min (76.2 %)			5 min	475 min (98.9 %)	22.9 %
008	129 min (26.8 %)	351 min (73.1 %)				480 min (100.0 %)	26.8 %
011	98 min (20.4 %)	325 min (67.7 %)	25 min (5.2 %)	32 min (6.6 %)		423 min (88.1 %)	23.1 %
013	112 min (23.3 %)	368 min (76.6 %)				480 min (100.0 %)	23.3 %
017	76 min (15.8 %)	396 min (82.5 %)	8 min (1.6 %)			472 min (98.3 %)	16.1 %
TOTAL	1236 min (25.7 %)	3452 min (71.9 %)	61 min (1.2 %)	32 min (0.6 %)	19 min	4688 min (97.6 %)	26.3 %

Tab. V. Distribution of state duration in 8 hour recordings fetuses group B

CASE NR	STATE 1	STATE 2	STATE 3-5	DECELERATION + REACTIVE FHR ALTERATION	TOTAL SLEEPING TIME	STATE 1 WITHIN TOTAL SLEEPING TIME
001	92 min (19.1 %)	234 min (48.7 %)	154 min (32.0 %)		326 min (67.9 %)	28.2 %
009	116 min (24.1 %)	261 min (54.3 %)	103 min (21.4 %)		377 min (78.5 %)	30.7 %
010	109 min (22.7 %)	218 min (45.4 %)	153 min (31.8 %)		327 min (68.1 %)	33.3 %
012	150 min (31.2 %)	294 min (61.2 %)		36 min (7.5 %)	444 min (95.5 %)	33.7 %
016	104 min (21.6 %)	347 min (72.2 %)		29 min (6.0 %)	451 min (93.9 %)	23.0 %
018	82 min (17.0 %)	186 min (38.7 %)	212 min (44.1 %)		268 min (55.8 %)	30.5 %
TOTAL	653 min (22.6 %)	1540 min (53.4 %)	622 min (21.5 %)	65 min (2.2 %)	2193 min (76.1 %)	29.7 %

for longer periods, relative duration of this pattern was 21.5%. With that relative duration of assumed REM-sleep FHR pattern diminished to 53.4%. The relative duration of assumed NREM-sleep FHR pattern remained nearly constant: 22.6%. Thus in 76.1% of total recording time a "sleeping" FHR pattern was seen and in 29.7% of "sleeping time" a NREM-sleep FHR pattern was identified. Thus **state distribution in group B was found to be nearly identical to state distribution in the neonate.** In 2 cases severe decelerations with consecutive FHR alterations occurred.

3.3 Duration of sleep cycles and ratio of NREM- and REM-periods within sleep cycles

Despite the striking difference between group A- and group B-fetuses in respect to the ratio of "sleep and wakefulness" no significant difference was found for both groups in respect to duration of sleep cycles and relative fractions of assumed NREM-sleep and REM-sleep within sleep cycles. Because of this fact data were pooled. According to Tab. VI mean duration of sleep cycles was 76.6 min, mean duration of NREM-periods within

Tab. VI. Duration of sleep cycles, absolute and relative duration of state 1 and state 2 periods within sleep cycle fetuses

CASE NR	NUMBER OF SLEEP CYCLES EVALUATED	MINIMUM DURATION OF SLEEP CYCLES	MAXIMUM DURATION OF SLEEP CYCLES	MEAN DURATION OF SLEEP CYCLES	MINIMUM DURATION OF STATE 1	MAXIMUM DURATION OF STATE 1	MEAN DURATION OF STATE 1 (% OF CYCLE)	MINIMUM DURATION OF STATE 2	MAXIMUM DURATION OF STATE 2	MEAN DURATION OF STATE 2 (% OF CYCLE)
001	3	65 min	96 min	78.0 min	14 min	24 min	20.0 min (27.2 %)	41 min	82 min	58.0 min (72.7 %)
002	4	54 min	130 min	82.7 min	9 min	33 min	18.0 min (23.6 %)	45 min	119 min	64.7 min (64.7 %)
003	7	25 min	83 min	60.5 min	8 min	33 min	16.7 min (28.1 %)	15 min	68 min	43.8 min (71.8 %)
004	4	62 min	126 min	85.0 min	18 min	25 min	20.7 min (25.8 %)	44 min	104 min	64.2 min (74.2 %)
005	7	56 min	79 min	66.1 min	16 min	33 min	21.8 min (32.9 %)	32 min	60 min	44.2 min (66.9 %)
006	5	51 min	90 min	64.0 min	19 min	32 min	22.0 min (35.5 %)	29 min	70 min	42.0 min (64.4 %)
007	4	50 min	83 min	69.7 min	15 min	24 min	18.7 min (28.0 %)	30 min	68 min	51.0 min (71.9 %)
008	4	86 min	134 min	105.0 min	23 min	37 min	28.5 min (27.8 %)	56 min	104 min	76.5 min (72.1 %)
009	2	59 min	82 min	70.5 min	22 min	33 min	27.5 min (38.7 %)	37 min	49 min	43.0 min (61.2 %)
010	3	77 min	109 min	94.3 min	22 min	27 min	25.0 min (27.0 %)	51 min	82 min	69.3 min (72.9 %)
011	4	82 min	113 min	93.0 min	21 min	27 min	23.6 min (26.3 %)	55 min	92 min	69.3 min (73.7 %)
012	3	69 min	82 min	76.0 min	14 min	20 min	17.3 min (22.7 %)	55 min	64 min	58.6 min (77.2 %)
013	3	87 min	121 min	103.3 min	19 min	30 min	24.6 min (22.3 %)	68 min	96 min	85.6 min (77.7 %)
016	4	52 min	84 min	61.7 min	8 min	26 min	18.2 min (29.4 %)	30 min	58 min	43.5 min (70.2 %)
017	5	64 min	106 min	79.2 min	11 min	20 min	15.2 min (19.2 %)	53 min	86 min	64.0 min (80.6 %)
018	2	67 min	71 min	69.0 min	11 min	19 min	15.0 min (21.5 %)	52 min	56 min	54.0 min (78.3 %)
	TOTAL 64			WEIGHTED MEAN 76.6 min			WEIGHTED MEAN 20.4 min (26.6 %)			WEIGHTED MEAN 56.6 min (73.7 %)

cycles was 20.4 min (26.6% of total duration of cycle) and mean duration of REM-periods within cycles was 56.6 min. Compared to values given above for the newborn infants, mean duration of sleep cycles and mean duration of NREM- and REM-sleep were slightly longer but values did not differ statistically.

3.4 Evaluation of fetal motor activity

Visual evaluation of our recording gave rise to the impression that in the group of postterm fetuses definitely more movement marks occurred compared to the fetuses near term. Our impression was, that the higher percentage of "wakefulness" within total recording time, which in some cases was accompanied by an abundant motor activity, was not the only reason and that motor activity was raised during "sleep" of postterm fetuses too. Therefore analysis was done in both respects. Because of the unequal distributions of times spend in all states the ratio of movement counts per duration of states again is used for comparison.

3.4.1 Comparison of motor activity in 8 hour recordings in fetuses of group A and group B

The ratio of total movement counts per total recording time gives a relative measure of general motor activity for intergroup comparison. For group A a ratio of .230 and for group B a ratio of .448 was calculated. This means that there was about 2 X more general motor activity in the postterm fetuses.

3.4.2 Comparison of sleep state related motor activity in fetuses of group A and group B

In 1.4 it was demonstrated that motor activity of the newborn infant is not evenly distributed in respect to NREM- and REM-sleep. This holds true for motor activity in the fetus as well, but whereas in the fetus near term (group A) ratios differ by a factor of 10 (0.29 and .297), in the postterm fetus the difference is less (.124 and .395) and values are somewhat similar to those in the newborn infants. Infact, motor activity is enhanced about threefold in NREM-sleep of postterm fetuses compared to fetuses near term.

3.4.3 Anencephaly

During the course of our investigations 2 cases of anencephaly, 23 and 36 weeks of gestation, were admitted to the ward and 8 hour recordings were done in both prior to termination of pregnancy. From Fig. 5 it can be seen that no distinct periodic changes in FHR pattern and motor activity occurred. The pattern seen throughout recordings was similar to a REM-sleep or a transitional pattern. Heart rate control on the whole seemed to be less stable.

4 Discussion

4.1 General considerations

FHR analysis is a main diagnostic tool for the perinatologist. In our opinion research in the field of FHR analysis in the past years has been directed

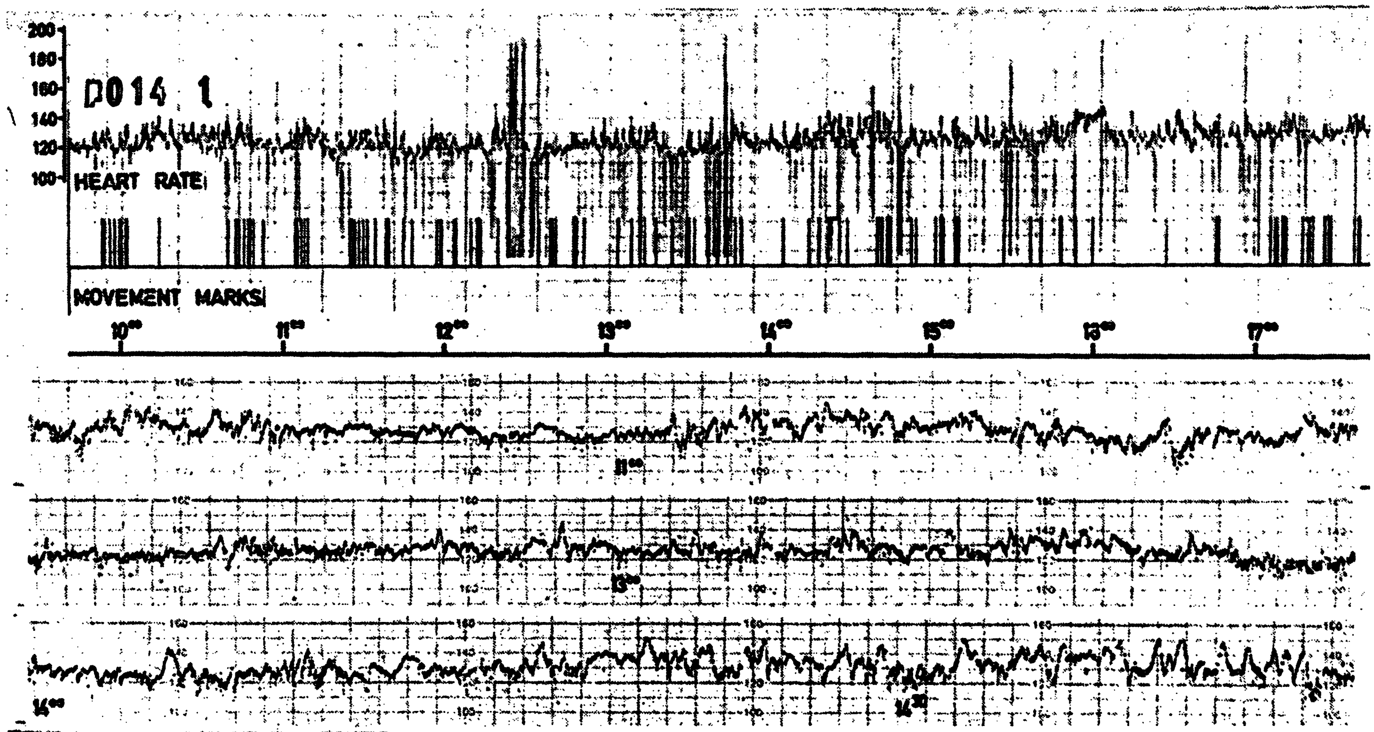


Fig. 5. Fetus (014)
Top: Compressed writeout of 8 hour recording of FHR and movement marks. Anencephalus of 36 weeks gestation. No clear-cut changes of FHR pattern can be detected.
Bottom: 3 segments of original FHR writeout (HEWLETT-PACKARD machine at 1 cm/min speed).
FHR is similar to a REM-sleep pattern, but less stable. Sometimes FHR looks like a transition from REM-sleep to NREM-sleep pattern, but no NREM-sleep follows.

mainly towards the relation between FHR alterations and fetal distress, whereas investigation of the "normal" variations of FHR patterns in the unstressed fetus and their regulating mechanisms has been neglected.

The existence of fetal "sleep" and "wakefulness" (or rest and activity) with concomittant changes of FHR macrofluctuation pattern has been postulated for some time. But distribution of these states along time, i.e. their sequential properties were not known in detail. Moreover, descriptions of FHR pattern changes attributed to these state changes were rather unprecise. Last not least there are no precise ideas whether and how other factors influence FHR pattern in the normal undisturbed fetus, except the fact that baseline decreases with advancing gestation, i.e. with cerebral maturation [1, 20, 60, 61] and the fact that variability increases [60, 61].

Only the knowledge and clear definition of the variation of physiologic FHR patterns can lead to a clearcut definition of pathologic patterns. Therefore new approaches to investigate normal FHR patterns, their variations and their underlying regulatory mechanisms have to be looked for. In doing so one should start to verify and investigate precisely factors, which according to our present knowledge seem to be of major importance and one of them is, to our mind, central nervous function. The fact that according to literature state related changes of newborn heart rate pattern do occur and the fact that fundamental differences in CNS function in the mature fetus near term and in the newborn infant may not be assumed were the basis for our comparative investigation of fetal and neonatal heart rate patterns and their concomitant states of CNS function.

4.2 Comments on results

Presuming that identical heart rate patterns in the newborn infant and in the fetus derive from identical or at least comparable states of central nervous function the following may be stated.

In the mature and undisturbed fetus sleep cycles of about 1 hour duration occur sequentially and periods of NREM-sleep and REM-sleep occur alternating within this cycle, their duration being roughly in a 1:2 to 1:3 ratio. Motor activity is unevenly distributed during a sleep cycle, **fetal movements generally are associated with REM-sleep (= state 2/4) and they are rare (startles) in NREM-sleep.** Central nervous arousal comparable to wakefulness in the newborn seems to be a rare phenomenon in the undisturbed fetus, at least when the mother is quietly lying in her bed. Synchronously with these sleep state changes variation of FHR pattern occurs and according to our analysis the most distinct variation is that of macrofluctuation amplitude whereas macrofluctuation frequency is less and baseline level inconsistently modulated. Because fetal movements are unevenly distributed in respect to state on one hand and on the other hand cause accelerations, variation of FHR pattern by state changes is enhanced. Therefore, on the basis of the above given assumption it can be said that spontaneously changing central nervous coordination or arousal is the predominating factor governing FHR pattern and its variation in fetal wellbeing.

Besides that there is suspicion that other factors, such as respiratory activity may modify FHR pattern additionally and distinctly. Recent publications about antepartum FHR recording support this idea [56, 61].

The most striking findings in the postterm fetuses of group B were first of all the fact that the ratio of sleep and "wakefulness" changed considerably: a state 3–5 like FHR pattern together with considerable motor activity was seen in about 20% of total recording time. Secondly motor activity was enhanced even during sleep states: the ratio of movement counts per state duration was significantly higher in REM-sleep (state 2/4) and in NREM-sleep compared to fetuses of group A. Because fetal movements generally were associated with accelerations FHR pattern during sleep states was modified as well. Contrary to that duration of sleep cycles and ratio of NREM- and REM-sleep were not altered significantly. At present we do not have a precise explanation for these findings of enhanced motor activity in postmaturity and it is in contrast to results of others [7, 46].

Whereas in one of the two cases with suspicion of beginning fetal distress (016) no alterations from the FHR pattern described above could be seen during the 8 hour recordings (except a deceleration when the patient sat up to empty her bladder, which was seen in case 11 of group A too), in the other case (009) during sleep states macrofluctuation amplitude was minimal. Still, even in this fetus a state of "wakefulness" of nearly 2 hours duration occurred and overall motor activity was raised.

The 2 cases of anencephaly were included in our investigation, because we excepted further insight in the relation of CNS function and FHR pattern. Contrary to an earlier publication [15] in which complete loss of macrofluctuation was found in anencephaly, 8 hour recordings in these 2 anencephalic fetuses showed macrofluctuation throughout the recordings but no distinct periodic changes of FHR and motor activity. The macrofluctuation pattern seen was similar to a REM pattern. It has been stated that NREM-sleep is the state with the strongest homoiostatic control and that infants with CNS lesions are frequently not able to achieve this stable state or to continue it over more than a few minutes [48]. This statement would be supported by our finding. Still one has to have in mind, that these 2 fetuses were 23 and 36 weeks of gestation and that absence of NREM-sleep may be an effect of cerebral immaturity too.

4.3 Consequences for clinical routine FHR monitoring

Present management of clinical routine antepartum FHR monitoring aims at the early detection of FHR alterations caused by subacute or chronic hypoxia and is based on the fact, that hypoxia leads to diminution, at last to loss of macrofluctuation amplitude and, if contractions are present to late deceleration.

For routine antepartum FHR recording generally a duration of 30 min is recommended, every two days to three times per day.

Our investigations revealed that diminution of macrofluctuation amplitude occurs cyclically in NREM-sleep for periods of up to 30 min and more, independent of hypoxia (see case 013). **Therefore a false suspicion of fetal distress may result from a 30 min routine FHR recording**, when it is started just at the beginning of a normal NREM-sleep period.

On the other hand at least in the beginning of fetal distress seemingly normal FHR patterns with enhanced motor activity occur prior and after periods of definitely suspect macrofluctuation (see case 009) and a false diagnosis of fetal wellbeing may result from a 30 min routine FHR recording, when it does not include the period of suspect macrofluctuation pattern.

Therefore the presently recommended 30 min duration for ante partum FHR recording may be too short for safe discrimination of a normal NREM-sleep FHR recording and a FHR recording indicating hypoxia. General results of antepartum detection of hypoxia presumably will be better if at least one complete sleep cycle of NREM-sleep and REM-sleep is recorded in a session of at least 1 hour duration.

The same holds true for fetal movement counting: because movements are rare to absent during NREM-sleep in a healthy fetus fetal movement counting should always be done simultaneously with FHR recording, and fetal state behavior, according to macrofluctuation pattern, should be taken into account.

At present we do not know why fetal motor activity was found to be enhanced in our group of postmature fetuses and if diminution would have occurred later with hypoxia. This at least could not be noticed in the 2 fetuses (009, 016) suspect of being slightly hypoxic at the time of recording. **In this respect our results are not in agreement with publications reporting diminution and/or cessation of fetal movements in the fetus in danger and further investigations are necessary.**

In our opinion simultaneous recording of FHR, fetal respiration and fetal movements, similar to polygraphic recording in the newborn may result in a much better insight into fetal central nervous control and its impairment by hypoxia.

We therefore have to develop methods of fetal polygraphy, practicable for clinical routine of fetal intensive care.

Summary

In order to investigate the influence of spontaneous changes of CNS activity on ante partum FHR and fetal motor activity state specific heart rate and motor activity patterns of newborn infants were compared with patterns seen in the fetus. Instantaneous FHR derived from abdominal FECG, the external tocogram and fetal movements as indicated by the mother via push button were recorded continuously for 8 hours on strip chart and analog tape. At least 4 days after parturition the same individuae, now newborn (except 2 anencephaly, who died during parturition) were observed for assessment of newborn infant state behavior. Heart rate and respiration again were recorded for 8 hours continuously and during the whole time close observation and protocol of the newborns states and all interesting events was performed. **Visual evaluation and computer analysis of recordings revealed that in the newborn infant state related heart rate pattern changes do occur and that identical heart rate patterns and their changes can be seen in the fetus too.** Definition of states according to typical and comparable heart rate patterns in the newborn and in the fetus was supported by taking into account newborn and fetal motor activity patterns.

Results

1.1 Newborn infant:

Our results with respect to the distribution of sleep and wakefulness as well as with respect to duration of sleep cycles and the distribution of NREM-sleep and REM-sleep within sleep cycles as defined from observational notes and recording of heart rate and respiration are in good agreement with literature data: **In 76.9% of total recording time the babies were asleep and 26.6% of total sleeping time was defined as NREM-sleep.** From our recordings a mean duration for a sleep cycle of 61.9 min, a mean duration for a REM-period of 43.2 min was calculated.
Motor activity was rare in NREM-sleep (startles), but more frequent in REM-sleep (state 2/4). Mean ratios of movement counts per state duration were .129 and .391 respectively.

1.2 Fetus

Ante partum recordings were divided in 2 groups. Fetuses less than 1 week postterm were affiliated to group A. Fetuses more than 1 week postterm were affiliated to group B.

1.3 Overall distribution of state duration in 8 hour recordings.

1.3.1 Group A

In 97.6% of total recording time FHR showed a pattern identical to the newborn NREM-sleep or REM-sleep heart rate patterns. In 26.3% of total "sleeping time" (which is total time of NREM- and REM-pattern) a NREM-sleep FHR pattern was found. A pattern corresponding to wakefulness in the neonate was seen in only 1.2% of total recording time.

1.3.2 Group B

A striking difference in the overall distribution of states was found in group B. Relative duration of FHR pattern comparable to the newborn heart rate pattern of wakefulness increased to 21.5% and relative duration of REM-sleep pattern decreased to 53.4% The realtive duration of NREM-sleep pattern remained constant.

2 Duration of sleep cycles and ratio of NREM- and REM-periods within sleep cycles

Despite the above mentioned differences in group A and group B fetuses the duration of sleep cycles and the ratio of NREM- and REM-periods in both groups did not differ significantly. Because of this fact data were pooled and mean duration of sleep cycles was 76.6 min, mean duration of NREM-periods within sleep cycle was 20.4 min (= 26.6% of total duration of sleep cycles) and mean duration of REM-periods was 56.6 min. **Compared to values given above for the newborn infants, mean duration of sleep cycles and periods of NREM- and REM-sleep were slightly longer but values did not differ statistically.**

3 Evaluation of fetal motor activity

Total movement counts per total recording time were .230 and .448 respectively for group A and group B fetuses. This means that there is more general motor activity in the postterm fetuses.
Calculation of NREM-sleep related motor activity in fetuses of group A and group B again demonstrates that **there is less motor activity during NREM-sleep compared to REM-sleep.** But whereas in group A the ratios of movement counts per state duration differ by a factor of 10 (.029 and .297 respectively), in the postterm fetus the difference is less (.124 and .359 respectively) and values are somewhat similar to those of the newborn infants.

4.1 Fetal distress

In two fetuses of group B suspicion of beginning fetal distress arose from routine clinical ante partum monitoring prior to our recording. In one of them no alterations from the FHR pattern described above could be seen, but in the other fetus during sleep states macrofluctuation amplitude was minimal. Still, even in this fetus a state of "wakefulness" of nearly 2 hours duration occurred and overall motor activity was raised.

4.2 Anencephaly

In two cases of anencephaly no distinct periodic changes in FHR pattern and motor activity occurred. The pattern seen throughout the recording was similar to a REM-sleep or transitional pattern. Heart rate control on the whole seemed to be less stable.

5 Clinical consequences

Presuming that identical heart rate patterns in the newborn infant and the fetus derive from identical or at least comparable states of CNS activity it may be concluded

that the latter is the predominating factor governing FHR pattern and its variation in fetal wellbeing. Synchronously with cyclic, state related variation of FHR pattern fetal motor activity changes too.
According to our results **the present management of ante partum clinical routine FHR monitoring, recommending a 30 min duration for recording seems to be unwise.** Results of FHR monitoring presumably will be better, if at least one complete sleep cycle of NREM-sleep- and REM-sleep FHR pattern is recorded in a session of at least 1 hour duration.
The same holds true for fetal movement counting, it should always be done simultaneously with FHR recording, and fetal state behavior, according to FHR pattern, should be taken into account.

Keywords: CNS activity, fetus, macrofluctuation, heart rate pattern, FHR monitoring, motor activity, newborn, polygraphy, respiration, sleep cycle, state behavior.

Zusammenfassung

Verhaltensweisen und verhaltensbedingte Herzfrequenz und motorische Aktivität des Neugeborenen und des Feten

Es wurde der Einfluß der zentralnervösen Koordination auf die fetale Herzfrequenzmusterung und auf die motorische Aktivität des Feten untersucht. Grundlage dieser Untersuchung war der Vergleich von typischen, den einzelnen Verhaltenszuständen beim Neugeborenen zugeordneten Herzfrequenz- und Bewegungsmustern mit Herzfrequenz- und Kindsbewegungsmustern beim Feten.
Dazu wurden zunächst die über das FEKG abgeleitete fetale Herzfrequenz, das externe Tokogramm und die von der Mutter gespürten und mit einem Tastschalter markierten Kindsbewegungen für 8 Stunden kontinuierlich registriert und auf Analogband aufgezeichnet. Mindestens 4 Tage nach der Geburt wurden die selben Kinder (mit Ausnahme von 2 Anencephali, die sub partu abstarben) wiederum für 8 Stunden beobachtet. In einem Protokoll wurden die Verhaltenszustände und die motorischen Bewegungen zeitlich genau festgehalten. Gleichzeitig wurde wiederum die Herzfrequenz und zusätzlich die Atmung registriert und auf Analogbandspeicher aufgezeichnet. **Die Auswertung der Protokolle und die visuelle Analyse der postpartalen Registrierungen ergab, daß bestimmte Herzfrequenzmuster und auch die motorische Aktivität in typischer Weise mit dem Verhaltenszustand korrelieren.** Daraufhin wurden die antepartalen Kurven analysiert. Es zeigte sich, daß die selben typischen Herzfrequenz- und Bewegungsmuster bei etwa gleicher Zeitverteilung auch in den Registrierungen der Feten zu finden waren. Aufgrund dieser Analogie kann als Ursache auch beim Feten ein regelmäßiger Wechsel der zentralnervösen Koordination, also der Verhaltenszustände angenommen werden.

Ergebnisse

1.1 Neugeborene

Unsere Ergebnisse in Bezug auf die Zeitverteilung der Verhaltenszustände, also in Bezug auf Schlaf- und Wachsein, in Bezug auf die Dauer der Schlafzyklen und in Bezug auf Schlaf- und Wachsein, in Bezug auf die Dauer der Schlafzyklen und in Bezug auf die Zeitverteilung von NREM- und REM-Schlaf innerhalb der Schlafzyklen stimmen gut mit den Literaturangaben überein. **In 76.9% der Gesamtbeobachtungszeit fand sich ein Schlafzustand und 26.6% der gesamten Schlafzeit wurde als NREM-Schlaf definiert.** Die mittlere Dauer des Schlafzyklus betrug 61.9 Min., die mittlere Dauer des NREM-Schlafs innerhalb des Schlafzyklus betrug 18.5 Min. (= 29% der Schlafzyklusdauer) und die mittlere Dauer des REM-Schlafs 43.2 Min.
Im NREM-Schlaf fand sich eine geringe motorische Aktivität (Startles), im REM-Schlaf war sie etwa um das Dreifache erhöht: Der Quotient aus der Zahl der Kindsbewegungen pro NREM- bzw. REM-Schlaf-Dauer betrug .129 bzw. .391.

1.2 Fetus

Die antepartalen Registrierungen wurden in 2 Gruppen unterteilt. Feten mit einer Schwangerschaftsdauer < 42 Wochen wurden der Gruppe A, Feten mit einer Schwangerschaftsdauer ⩾ 42 Wochen wurden der Gruppe B zugeordnet.

1.3 Zeitverteilung der Verhaltenszustände

1.3.1 Gruppe A

Bei den Feten der Gruppe A fand sich in 97.6% der Gesamtbeobachtungszeit ein Herzfrequenzmuster, das dem Herzfrequenzmuster beim Neugeborenen im NREM- oder REM Schlaf entsprach. In 26.3% dieser gesamten „Schlafzeit" fand sich ein Herzfrequenzmuster, das dem NREM-Schlaf entsprach. Ein Herzfrequenzmuster, wie man es beim wachen Neugeborenen sieht, fand sich nur in 1.2% der Gesamtbeobachtungszeit.

1.3.2 Gruppe B

Im Vergleich mit der Gruppe A zeigte sich ein erheblicher Unterschied in der Verteilung der verhaltenszustandstypischen Herzfrequenzmuster, bezogen auf die Gesamtbeobachtungsdauer. Ein Herzfrequenzmuster, das beim wachen Neugeborenen zu sehen ist, fand sich in 21.5% der Gesamtbeobachtungsdauer, der Anteil des für den REM-Schlaf des Neugeborenen typischen Musters betrug 53.4%. Der Anteil des für den NREM-Schlaf typischen Musters war im Vergleich zur Gruppe A unverändert.

2 Dauer der Schlafzyklen und Verhältnis von NREM- und REM-Schlaf-Herzfrequenzmuster innerhalb der Schlafzyklen

Trotz der oben angegebenen unterschiedlichen Verteilung der einzelnen verhaltenszustandstypischen Hersfrequenz-

muster in Bezug auf die Gesamtbeobachtungszeit in den Registrierungen der Gruppe A und B ergaben sich keine signifikanten Unterschiede in Bezug auf die Dauer der Schlafzyklen und in Bezug auf das Verhältnis von NREM- und REM-Schlaf innerhalb des Schlafzyklus. Deshalb wurden die Daten beider Gruppen bei dieser Auswertung gepoolt. Es wurde eine mittlere Dauer des Schlafzyklus von 76.6 Min., eine mittlere Dauer der NREM-Perioden von 20.4 Min. (= 26.6% der Schlafzyklusdauer) und eine mittlere Dauer der REM-Perioden von 56.6 Minuten errechnet. Im Vergleich mit den entsprechenden Daten der Neugeborenen ergaben sich somit etwas längere Dauern, aber der Unterschied war statistisch nicht signifikant.

3 Motorische Aktivität der Feten

Der Quotient aus der Gesamtzahl aller Kindsbewegungen und der Dauer der Beobachtungszeit als generelles Maß für die motorische Aktivität war 0.230 bei den Feten der Gruppe A und 0.448 bei den Feten der Gruppe B. Letztere hatten also eine etwa doppelt so starke Bewegungsaktivität.

Die Berechnung des Quotienten aus Anzahl der Kindsbewegungen und Dauer der NREM- bzw. REM-Perioden ergab wiederum, wie bei den Neugeborenen, eine größere Bewegungsaktivität im REM-Schlaf. Während jedoch in der Gruppe A die Quotienten für NREM- und REM-Phasen 0.029 und 0.297 betrugen, die Bewegungsaktivität im REM-Schlaf also 10 mal stärker war als im NREM-Schlaf, betrugen sie bei den Feten der Gruppe B 0.124 bzw. 0.359. Diese stärkere Bewegungsaktivität der übertragenen Feten ist also der Bewegungsaktivität der Neugeborenen vergleichbar.

4.1 Fetale Notsituation

Bei 2 Feten der Gruppe B ergab sich aus der klinischen Intensivüberwachung der Verdacht auf eine beginnende fetale Notsituation. In einem Fall ergab sich bei der Dauerregistrierung kein Unterschied in der Herzfrequenzmusterung im Vergleich zu den anderen Registrierungen der Gruppe B. Im anderen Falle zeigte sich während des NREM- und REM-Schlafs eine verminderte Makrofluktuationsamplitude. Aber auch bei diesem Feten zeigte sich eine zweistündige Phase mit einem Herzfrequenzmuster, wie es typischerweise beim wachen Neugeborenen zu sehen ist und die Bewegungsaktivität war insgesamt, wie bei allen Feten der Gruppe B, erhöht.

4.2 Anencephalie

In 2 Dauerregistrierungen bei Anencephalus zeigte die Herzfrequenzmusterung keine deutlichen wechselhaften Änderungen. Das registrierte Muster entsprach demjenigen, das für den REM-Schlaf beim Neugeborenen typisch ist. Insgesamt schien die Regulation der Herzfrequenz instabil.

5 Konsequenzen für die Klinik

Nimmt man an, daß identische Herzfrequenzmuster beim Neugeborenen und beim Feten Ausdruck der selben oder zumindesten vergleichbarer zentralnervöser Koordinationszustände sind, dann muß man schließen, daß bei reifen Feten in gleicher Weise wie beim Neugeborenen ein regelmäßiger Wechsel der zentralnervösen Koordination stattfindet und daß beim Feten ebenso wie beim Neugeborenen der zyklische Wechsel der zentralnervösen Koordination der wesentliche Faktor für die spontane Variation des Herzfrequenzmusters und der motorischen Aktivität ist.

In Anbetracht der vorgelegten Ergebnisse erscheint das gegenwärtige Management der antepartalen CTG-Intensivüberwachung mit jeweils 30-minütiger CTG-Registrierung nicht optimal. Vermutlich kann die Treffsicherheit der CTG-Intensivüberwachung verbessert werden, wenn mindestens ein kompletter Schlafzyklus von NREM- und REM-Schlaf-Herzfrequenzmuster kontinuierlich über mindestens eine Stunde registriert wird.

Dasselbe gilt für die Registrierung und Auswertung von fetalen Kindsbewegungen. Diese Überwachungsmethode sollte nur unter Beachtung des fetalen Verhaltenszustandes, also bei gleichzeitiger CTG-Registrierung und Identifizierung des momentanen Verhaltenszustandes aus dem Herzfrequenzmuster durchgeführt werden.

Schlüsselwörter: Atmung, Fetus, Herzfrequenzmuster, Herzfrequenzregistrierung, Makrofluctuation, motorische Aktivität, Neugeborenes, Polygraphie, Schlafzyklus, Verhaltenszustand, ZNS-Aktivität.

Résumé

Etats de comportement, état de rythme cardiaque relaté et échantillons d'activité motrice chéz le nouveau-né et le foetus ante partum

I. Une étude comparative

Nous avons étudié l'influence de la coordination nerveuse centrale sur l'échantillonnage du rythme cardiaque foetal et sur l activité motrice du foetus. Pour cela, nous avons commencé par comparer les échantillons de rythme cardiaque et de mouvement typiques et particuliers aux divers états de comportement du nouveau-né avec les échantillons de rythme cardiaque et de mouvement du foetus.

A cet effet nous avons d.abord enregistrç et relevç sur bande analogique pendant huit heures consçcutives le rythme cardiaque foetal dçrivç sur ECG foetal, le tocogramme externe et les mouvements foetaux ressentis par la mére et marqçs á l.aide d.un compteur de palpation' Quatre jours au moins après la naissance, les mêmes enfants (à l'exception de deux anencéphales morts sub partu) ont subi à nouveau les mêmes observations pendant huit heures consécutives. Nous avons noté le temps très précis des états de comportement et des mouvements moteurs. Parallèlement, nous avons enregistré le rythme cardiaque ainsi que la respiration et les avons relevés sur bande accumulatrice analogique. L'évaluation de tous ces relevés et l'analyse visuelle des enregistrements après l'accouchement ont montré que certains échantillons de rythme cardiaque et aussi l'activité motrice suivent une corrélation spécifique avec l'état de comportement,ce qui

nous a amenés à analyser les courbes enregistrées avant l'accouchement. Nous avons pu alors observer chez les foetus également les mêmes échantillons typiques de rythme cardiaque et de mouvement avec une répartition de temps à peu près identique. En raison de cette analogie, on peut supposer à l'origine aussi chez les foetus une alternation régulière de la coordination nerveuse centrale, c.à.d. des états de comportement.

Résultats

1.1 Nouveaux-nés

Nos résultats relatifs à la répartition temporelle des états de comportement, c.à.d. au sommeil et à l'éveil, relatifs à la durée des cycles de sommeil et relatifs à la répartition temporelle du sommeil et relatifs à la répartition temporelle du sommeil NREM et REM à l'intérieur des cycles de sommeil concordent bien avec les données relevées en littérature. **On a enregistré un état de sommeil dans 76,9% de la période totale d'observation, et 26,6% de la période totale de sommeil ont été définis comme sommeil NREM.** La durée moyenne du cycle de sommeil a été de 61,9 min., la durée moyenne du sommeil NREM à l'intérieur du cycle de sommeil) et la durée moyenne du sommeil REM de 43,2 min.
Dans le sommeil NREM on a pu observer une légère activité motrice (Startles) qui a à peu près triplé d'intensité dans le sommeil REM: Le quotient du nombre des mouvements foetaux par durée de sommeil NREM et REM s'est chiffré respectivement à .129 et .391.

1.2 Foetus

Les enregistrements avant l'accouchement ont été répartis en deux groupes. Les foetus avec une durée de grossesse < 42 semaines ont été réunis dans un groupe A et les foetus avec une durée de grossesse ⩾ 42 semaines dans un groupe B.

1.3 Répartition temporelle des états de comportement

1.3.1 Groupe A

Dans les foetus du groupe A on a relevé dans 97,6% de la période totale d'observation un échantillon de rythme cardiaque qui a correspondu à l'échantillon de rythme cardiaque chez le nouveau-né dans le sommeil NREM ou REM. Dans 26,3% de ce «temps de sommeil» total on a pu observer un échantillon de rythme cardiaque qui a correspondu au sommeil NREM. Un échantillon de rythme cardiaque, tel qu'on le voit chez le nouveau-né en éveil, n'a pu être observé que dans 1,2% de la période totale d'observation.

1.3.2 Groupe B

En comparaison avec le groupe A, on a observé une très grosse différence dans la répartition des échantillons de rythme cardiaque, relevé chez le nouveau-né en éveil, s'est manifesté dans 21,5% de la durée totale d'observation, la part de l'échantillon typique pour le sommeil REM du nouveau-né s'est élevée à 53,4%. La part de l'échantillon typique pour le sommeil NREM est restée inchangée en comparaison avec le groupe A.

2 Durée des cycles de sommeil et rapport entre les échantillons de rythme cardiaque en sommeil NREM et REM à l'intérieur des cycles de sommeil

En dépit de la répartition différenciée citée plus haut des divers échantillons de rythme cardiaque typiques pour l'état de comportement en rapport avec la période totale d'observation dans les enregistrements des groupes A et B, on n'a trouvé aucune différence significative à propos de la durée des cycles de sommeil et du rapport entre le sommeil NREM et REM à l'intérieur du cycle de sommeil. C'est pourquoi on a rassemblé les données des deux groupes dans cette évaluation. On a alors obtenu une durée moyenne du cycle de sommeil de 76,6 min., une durée moyenne des périodes NREM de 20,4 min. (= 26,6% de la durée du cycle de sommeil) et une durée moyenne des périodes REM de 56,6 min. **En comparaison avec les données conformes des nouveaux-nés, on a obtenu ainsi des durées un peu plus longues, mais la différence est insignifiante et d'aucune importance statistique.**

3 L'activité motrice des foetus

LLe quotient du nombre total des mouvements foetaux et de la durée de la période d'observation, considéré comme mesure générale pour l'activité motrice, a été de 0.230 chez les foetus du groupe A et de 0.448 chez les foetus du groupe B, soit à peu près deux fois plus élevé chez ces derniers.
Le calcul du quotient du nombre des mouvements foetaux et de la durée des périodes NREM et REM a montré à son tour, comme pour les nouveaux-nés, **une activité motrice plus grande dans le sommeil REM.** Tandis que les quotients ont été, toutefois, dans le groupe A de 0.029 et de 0.297 pour les phases NREM et REM, c.à.d. que l'activité motrice a été dix fois plus forte en phase de sommeil REM, ils se sont chiffrés respectivement à 0.124 et 0.359 chez les foetus du groupe B. Cette activité motrice plus forte des foetus ayant dépassé le terme est donc comparable à celle des nouveaux-nés.

4.1 La situation d'urgence foetale:

Chez deux foetus du groupe B, la surveillance intensive clinique a fait craindre le début d'une situation d'urgence foetale. Dans un cas on n'a observé dans l'enregistrement continu aucune différence dans l'échantillonnage du rythme cardiaque comparé avec les autres enregistrements du groupe B. Dans l'autre cas, on a observé une amplitude réduite de macrofluctuation pendant le sommeil NREM et REM. Chez ce foetus également s'est manifestée une phase de deux heures avec un échantillon de rythme cardiaque, phénomène typique chez le nouveau-né en éveil, et l'activité motrice a été dans l'ensemble élevée comme chez tous les foetus du groupe B.

4.2 Anencéphalie

Dans deux enregistrements continus d'anencéphalie, l'échantillonnage de rythme cardiaque n'a montré aucun changement alternatif prononcé. L'échantillon enregistré a été analogue à celui typique pour le sommeil REM chez le nouveau-né. Dans l'ensemble, la régulation du rythme cardiaque a paru instable.

5 Conséquences pour la clinique

A supposer que les échantillons identiques de rythme cardiaque chez le nouveau-né et chez le foetus traduisent des états de coordination nerveuse centrale identiques ou au moins comparables, **on doit en conclure qu.une alternation régulière de la coordination nerveuse centrale s.opère chez les foetus matures de même manière que chez les nouveaux-nés** et que, chez le foetus comme chez le nouveau-né, l'alternation cyclique de la coordination nerveuse centrale constitue le facteur essentiel pour la variation spontanée de l'échantillon du rythme cardiaque et de l'activité motrice.

En considération des résultats obtenus, le «management» actuel de la surveillance intensive CTG antepartale avec, chaque fois, un enregistrement CTG de 30 min' ne semble pas être optimal. Il est probable qu'on puisse améliorer la précision de la surveillance intensive CTG en enregistrant au moins un cycle complet de sommeil d'échantillon de rythme cardiaque en sommeil NREM et **REM de façon continue pendant une heure au minimum.**

Il en est de même pour l.enregistrement et l'évaluation des mouvements foetaux. Cette méthode de surveillance devrait être appliquée à la condition exclusive d'observation de l'état de comportement foetal, c.à.d. en enregistrant par CTG et en identifiant en même temps l'état de comportement momentané déduit de l'échantillon de rythme cardiaque.

Mots-clés: Activité CNS, cycle de sommeil, échantillon de rythme cardiaque, enregistrement du rythme cardiaque foetal, état de comportement, foetus, macrofluctuation, nouveau-né, polygraphie, respiration d'activité motrice.

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